SYSTEM DEVELOPMENT FOR MARS ENTRY IN SITU RESOURCE UTILIZATION

Svetozar Popović[1], Robert W. Moses[2], and Leposava Vušković[1]

[1] *Old Dominion University, Norfolk, VA*

[2] **NASA Langley Research Center, Hampton, VA**

Mars entry ISRU is an attempt to harvest some of the orbital energy that is transferred into heat during deceleration

There are several possible types of maneuvres for deceleration at Mars.

Two of them have been demonstrated ;

direct entry, Viking –type conservative approach with all energy wasted into atmospheric heat transfer;

aerobraking , where the energy loss is redistributed over several passages thereby some of the fuel was saved…

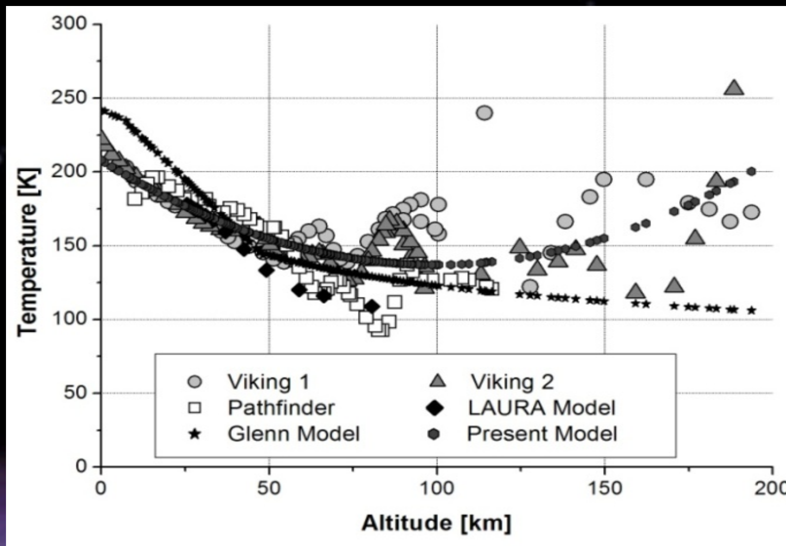
the third, aerocapture, has been intensively studied…

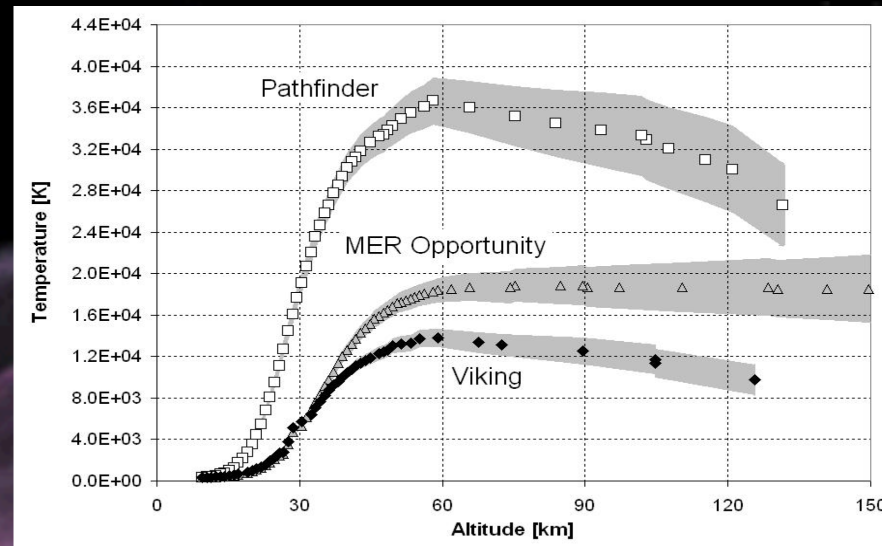
In all these cases the mechanical energy in excess of 10 GJ is wasted into heating the spacecraft and Martian atmosphere …

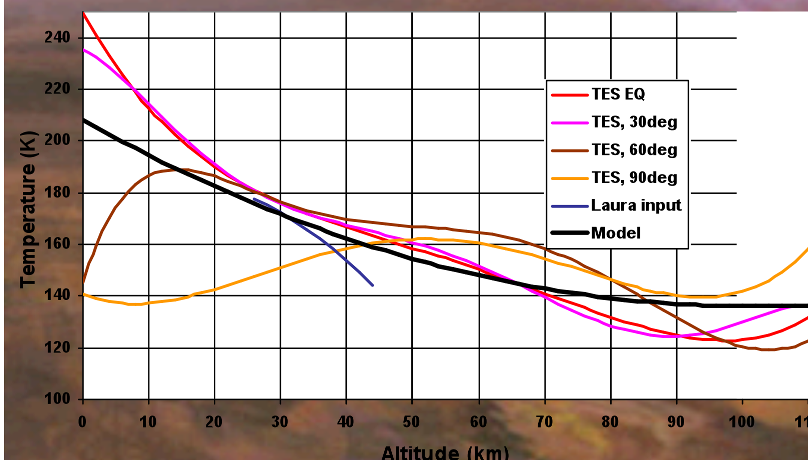
In direct entry maneuvre the dissipated power is counted **in 100 MW** , in the aerobraking maneuvre this rate is reduced to order of **MW**, but spread over time counted in tens of minutes …while MSL can dispose of about **100 W.**

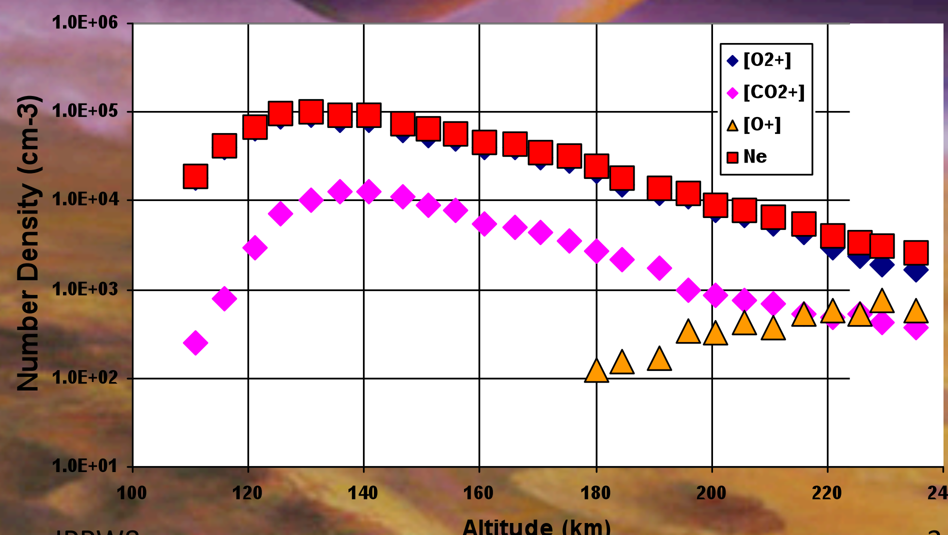
Is there place for science here?

Some environmental properties of Martian atmosphere with consequences to MARS entry ISRU





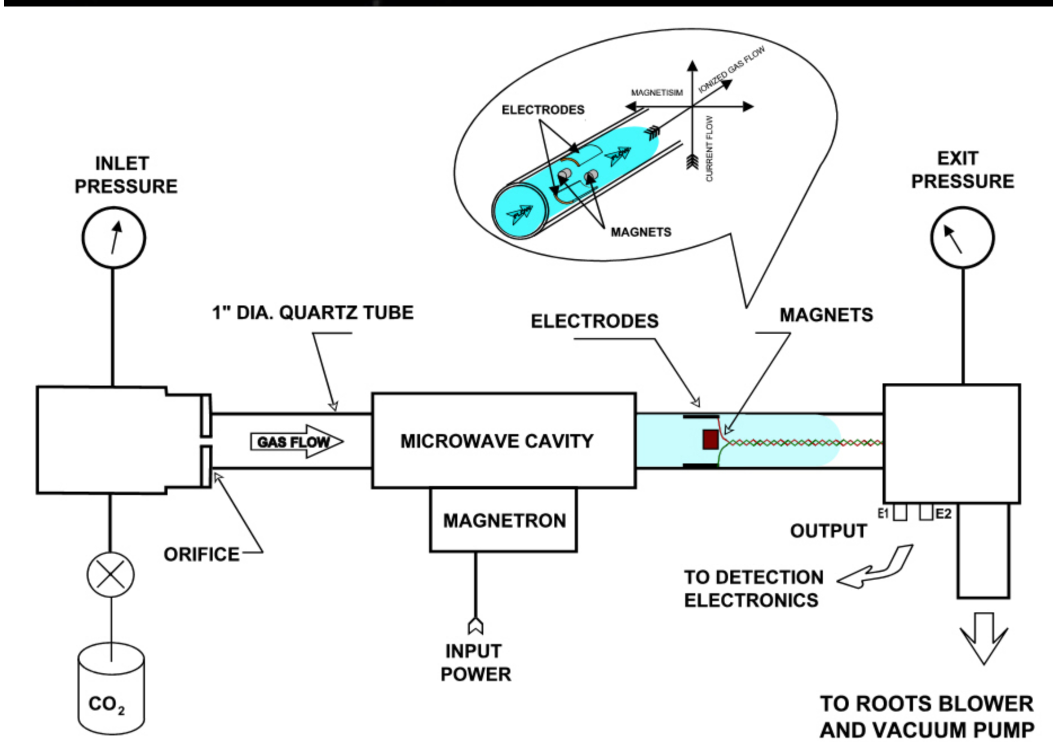


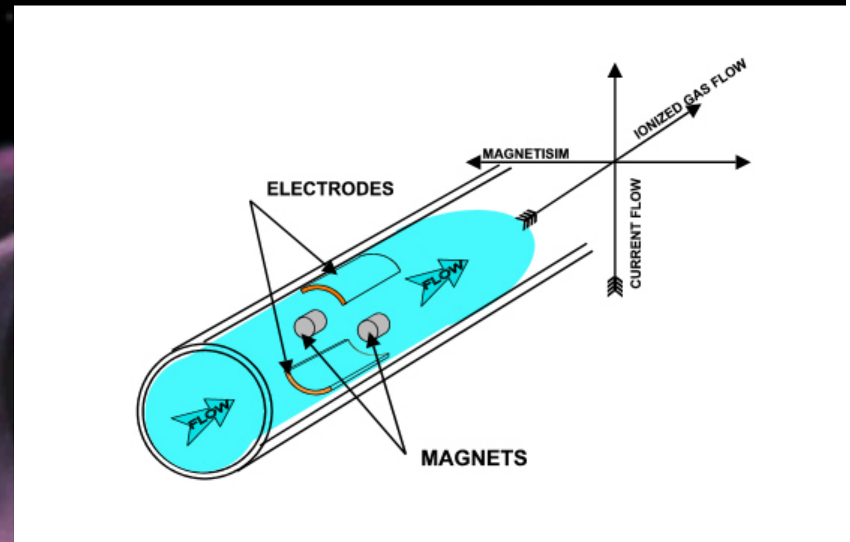


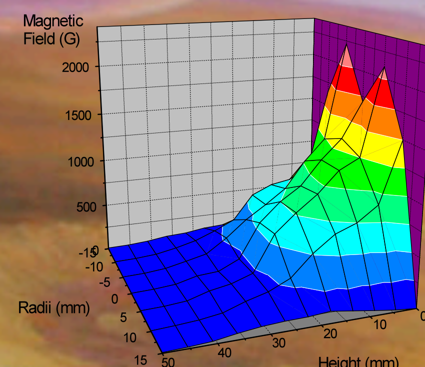
COMPONENTS OF MARS ENTRY ISRU SYSTEM

- Modular MHD generator matrix;
- Electrical current distribution unit;
- Active thermal shield cooling and entry communication black-out mitigation subsystem;
- Autonomously powered subsystem for active fluid-cooling of temperature sensitive components;
- Resistive load network for heat redistribution over the spacecraft;
- Oxygen harvesting and separation unit;
- Rigid, thermo-resistant inflatable container for oxygen/carbon dioxide storage.

Magnetohydrodynamic power generator

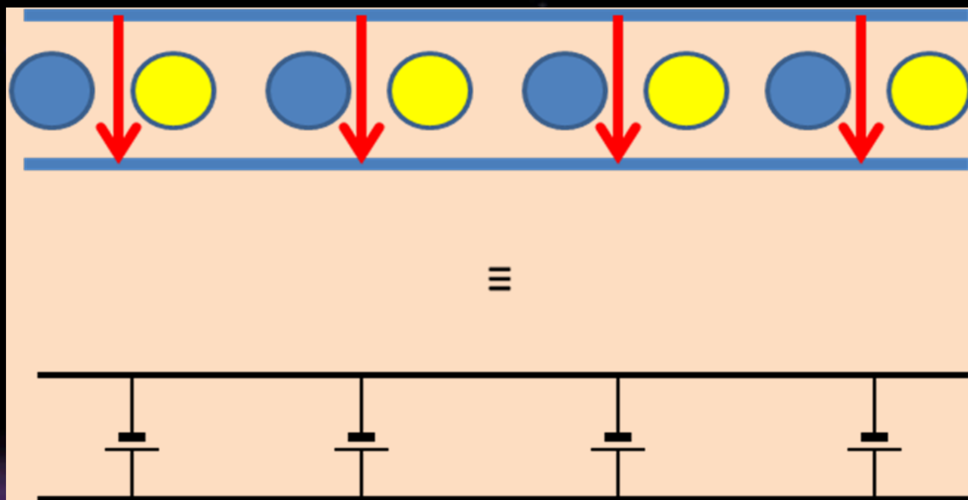


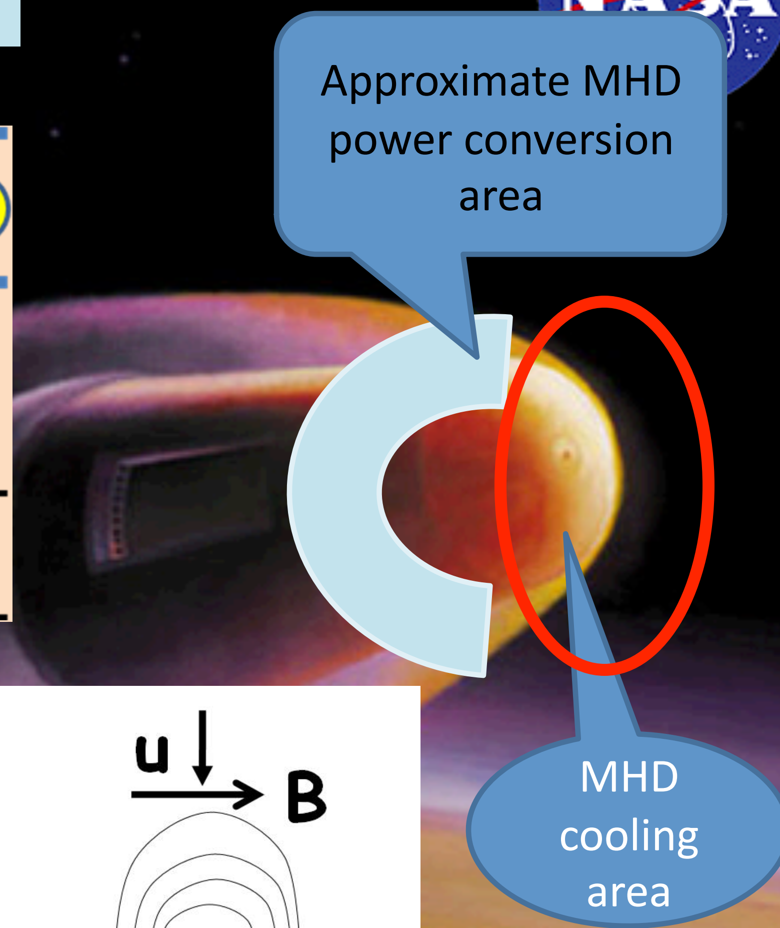


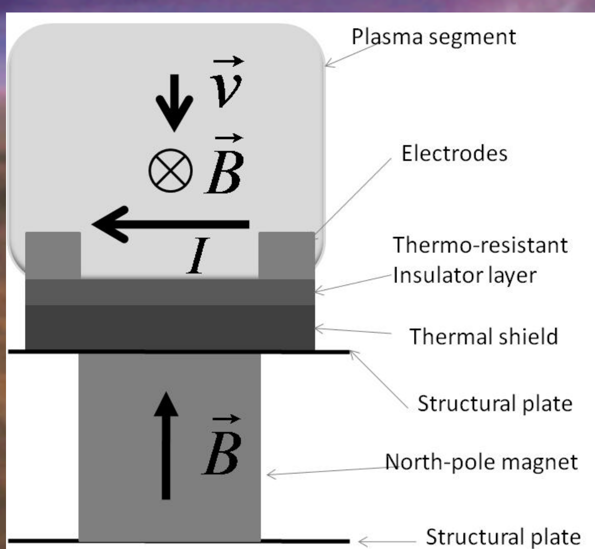


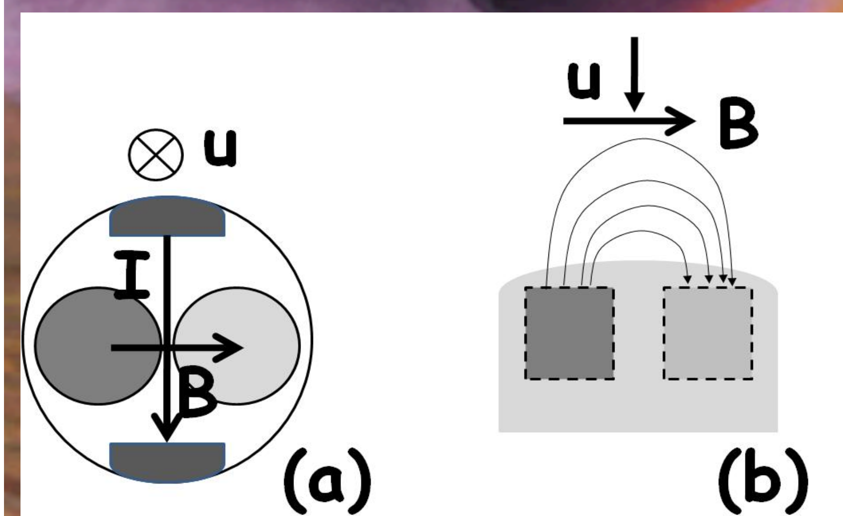
- External type
- Based on thermally shielded Co_5Sm magnets
- at M=2 the model generated 0.15 W per cm^2

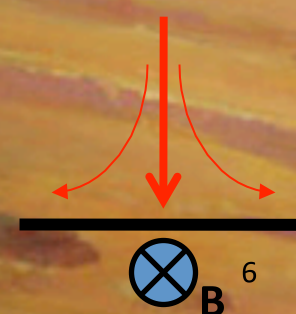
MHD generator matrix











How to use MHD-converted power?

- Active thermal shield cooling and entry communication black-out mitigation subsystem:
  - Ion/electron sheath manipulation/separation
    - MHD effect
    - Floating electric collector system
  - Dual-frequency antenna concept
  - Laboratory validation of concepts

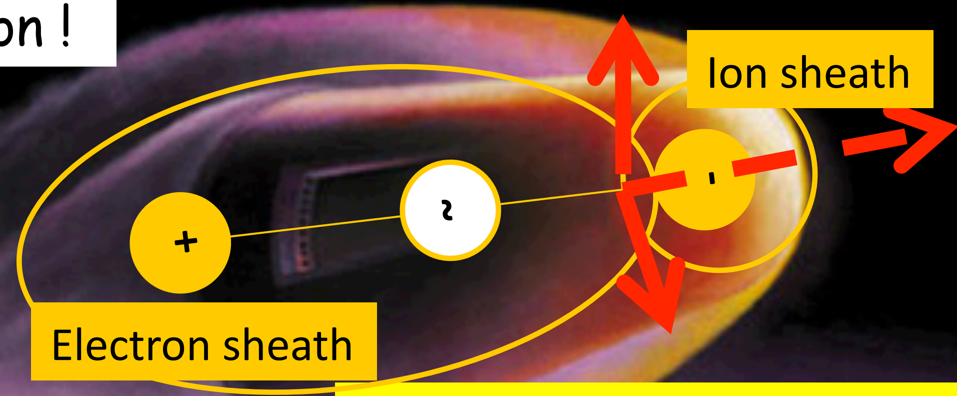
- Autonomously powered subsystem for active fluid-cooling of temperature sensitive components:
  - Temperature resistive capillary heat exchangers;
  - Choice of working fluid;
  - Pumps;

- Resistive load network for heat redistribution over the spacecraft;
  - Reconverts electric power to heat in remote areas of the spacecraft;

Blackout Mitigation

Theory ?

No, just the sheath manipulation !



Other methods:

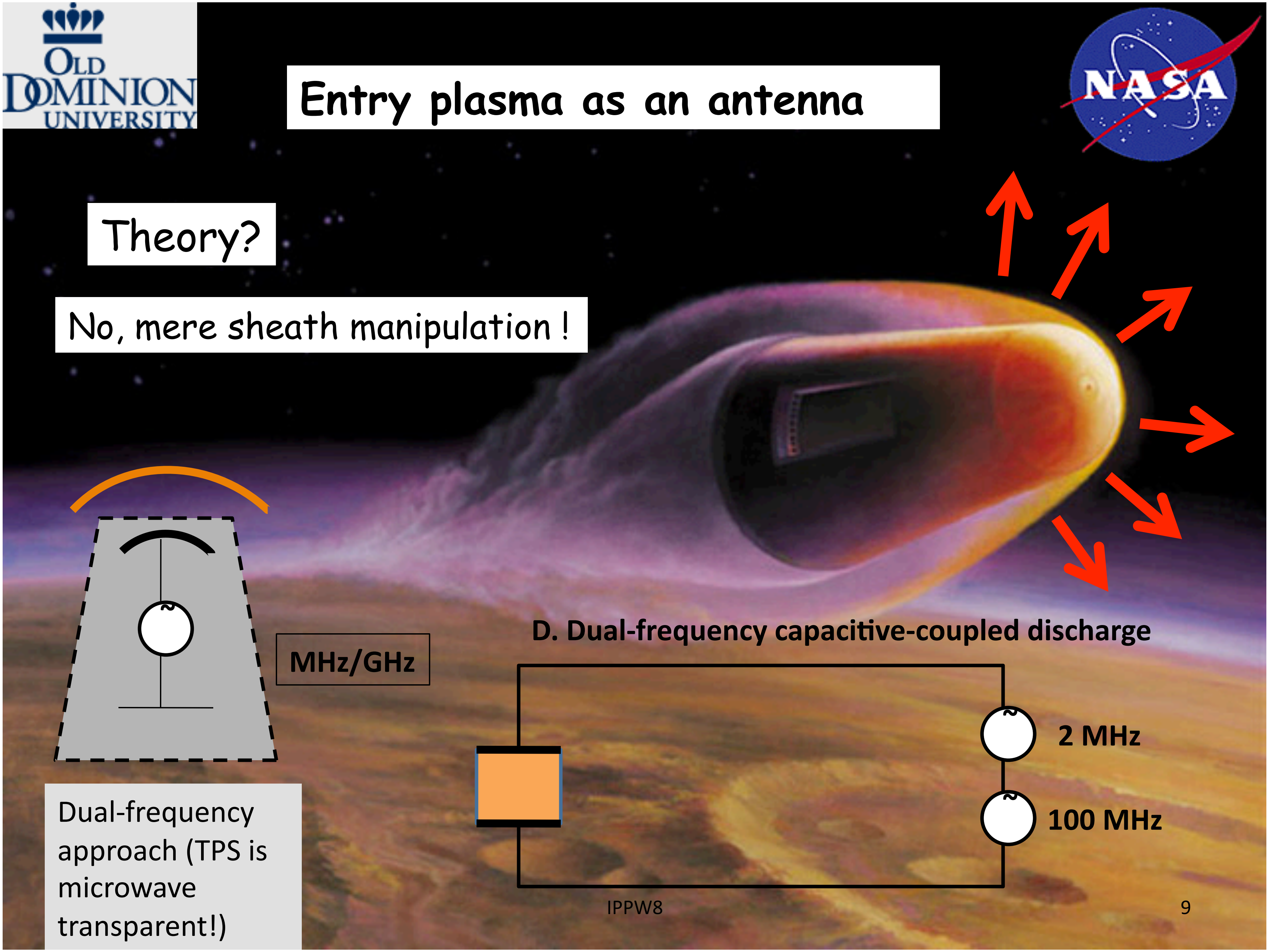
B. Electrodynamic double layer (magnets are already on board)

C. Magnetic window (probably too heavy for application)

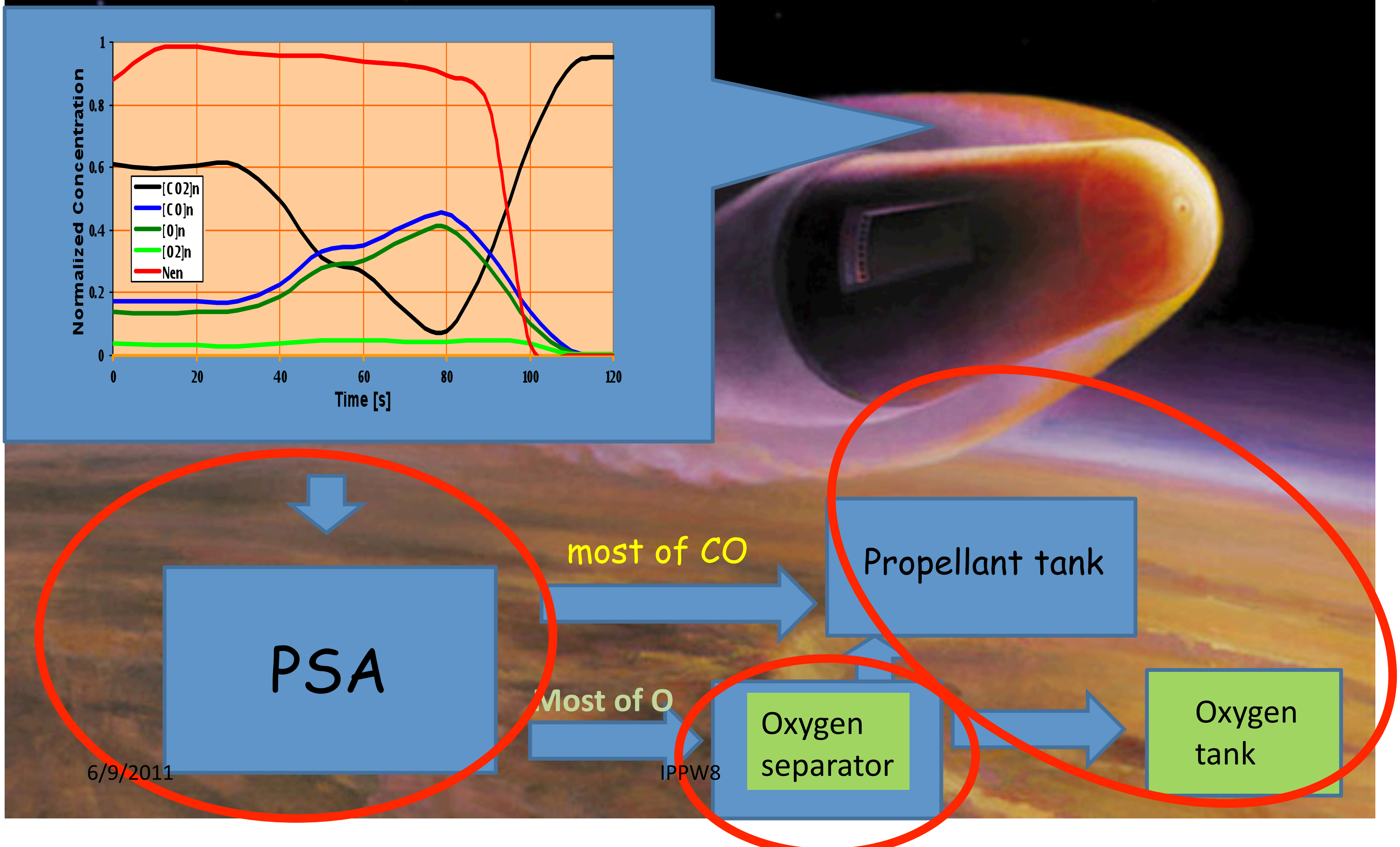
A. Floating probe method

- 100ns pulse repetitive (DB tolerant!)
- Repetition rate 200 kpps
- 100 ns time windows for communication

Entry plasma as an antenna



Oxygen harvesting system



Oxygen Separator

Oxygen separation technologies are based on several material candidates:

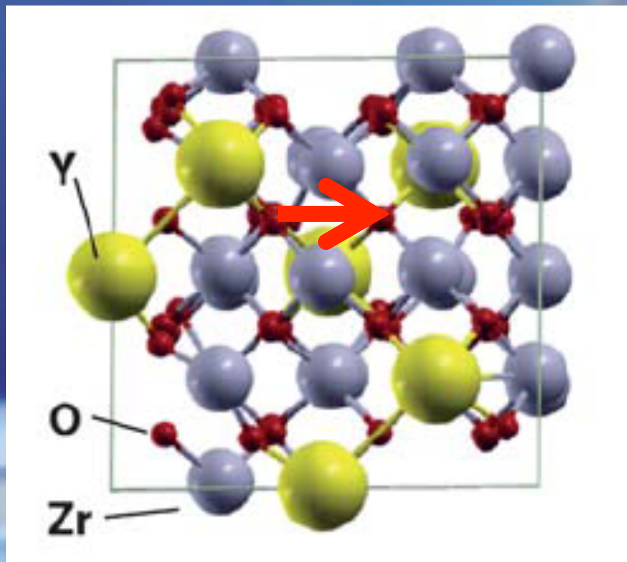
(i) vacancy diffusion through nano-crystallite solid oxide electrolytes, such as yttria stabilized zirconia (YSZ),

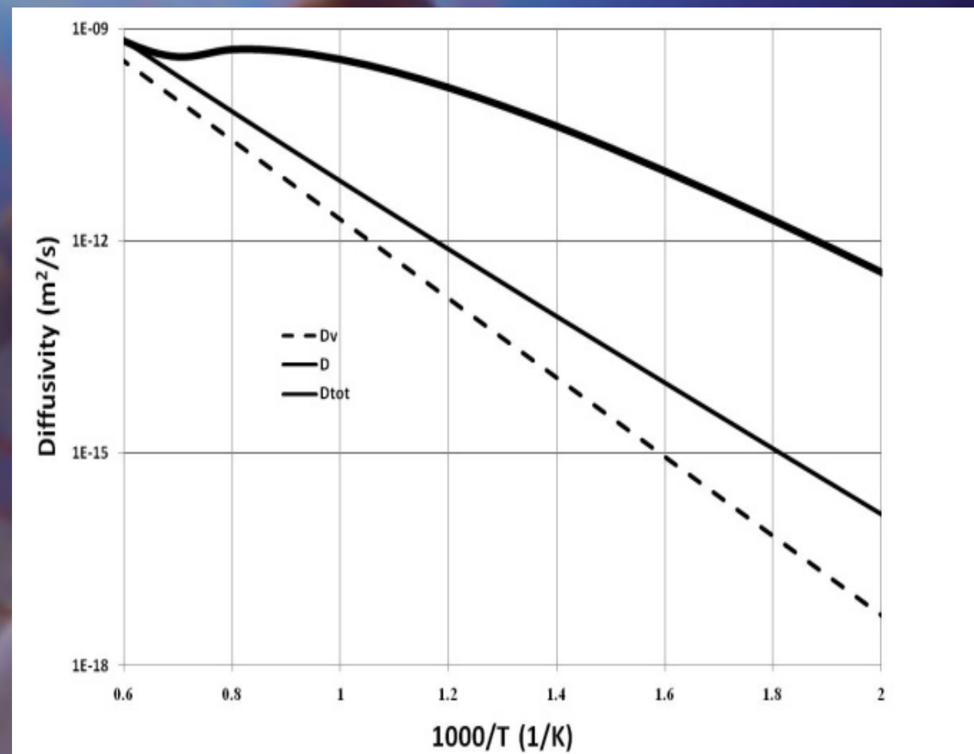
(ii) selective oxygen diffusion through silver,

(iii) oxygen separation through erbia stabilized bismuth.

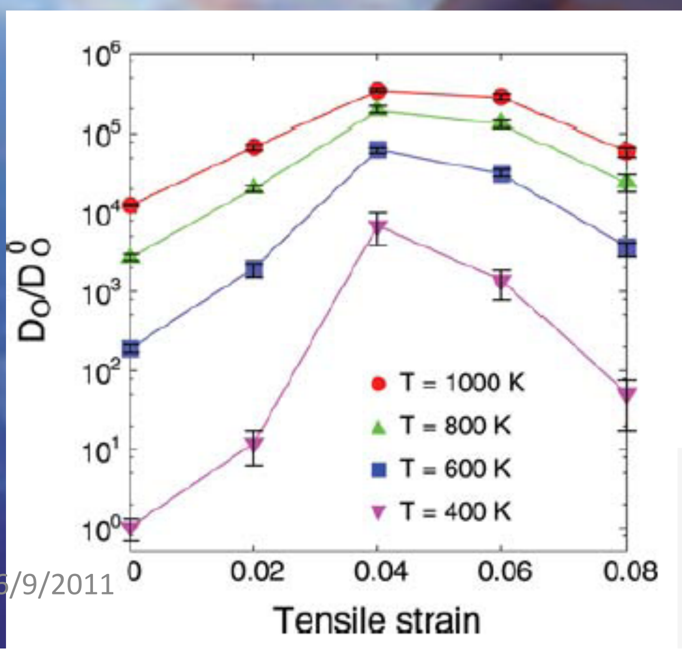
(iv) a number of polymer and ceramic oxide materials that are currently used in the fuel cell technologies may serve in the oxygen preprocessing phases.

YSZ



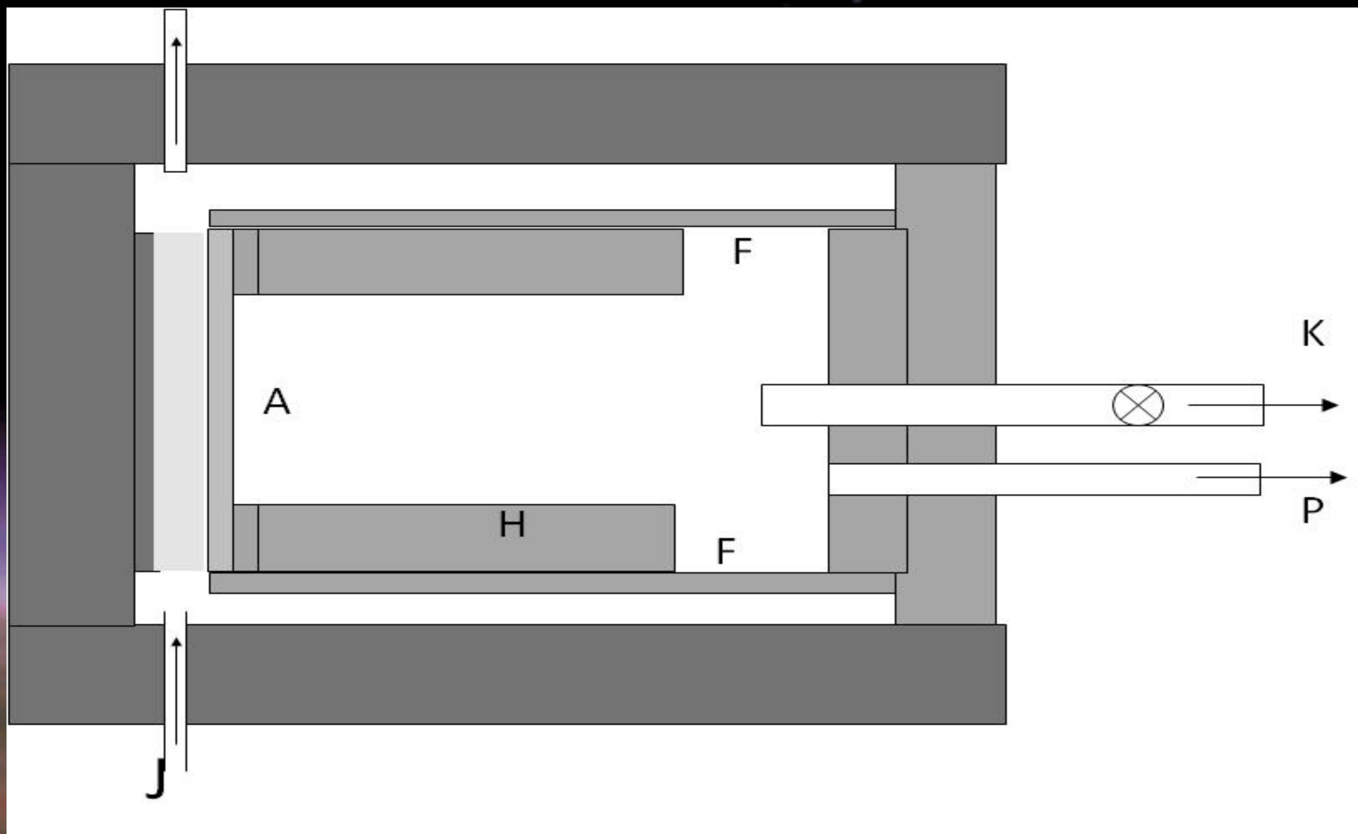


Knöner, G. etal,, "Enhanced oxygen diffusivity in interfaces of nanocrystalline $ZrO_2\_Y_2O_3$", *Proc.of the Nat. Acad. of Sciences of the U.S.A*, **100**, 3870-3873 (2003).



Kushima, A., and Yildiz, B., "Oxygen ion diffusivity in strained yttria stabilized zirconia: where is the fastest strain?", *Journal of Materials Chemistry*, **20**, 4809-4819 (2010).

Material testing chamber for oxygen separation



Oxygen separation test cell: A – diffusion membrane, H – heater, F - thermal shield, K - to mass spectrometer/inflatable oxygen container, P – to pressure gauge, J - Martian entry simullant mixture (in/out),.

Pressure swing adsorption

-Widely adopted technology for industrial oxygen separation from air
-Potentially useful as a first stage separator;
-Pressure swing of interest is 10^2 to 10^4 Pa – extension of "Vacuum PSA"

Challenges:

- Molecular sieve for CO, O_2 separation;
- High temperature pressure swing;
- Charged particle effects;
- Adsorber bed mass;

Inflatable containers for oxygen and propellant tanks

Design conditions:

Inflation manifold pressure 0.5 – 3 kPa (based on the entry plasma stagnation pressure)

Gas temperature (estimated, without gas cooler) 100 – 1000+ K

Ambient pressure 100-1000 Pa

Volume ~ 1 m^3 per 1 m^2

Materials – Nextel, Kapton, Kevlar …

Summary

Potential benefits of using Mars entry ISRU technologies are impressive :

	Direct Entry	Multi-Pass Orbit
Harvested Energy (Per m² MHD per orbit) No seed / ~~seeded~~ (Macheret et.al., 2004)	14 MJ / nc	~~0 /~~ 500 MJ
Energy Storage mass (Per m² MHD per orbit) SMES without/with CNT technology	100 kg / 10 kg	3000 kg / 200 kg
Available O_2/CO_2 (Per m² scoop area per orbit) for the atmospheric densities shown	30 kg / 42 kg 2×10^{-4} kg/m³	145 kg / 200 kg 8×10^{-5} kg/m³
Harvested O_2 (Per m² MHD area per orbit)	1.5 kg (if initially CO_2)	55 kg (if initially CO_2)
MHD Mass (Per m² MHD area per orbit)	100 kg [25]	100 kg [25]

[courtesy **Robert W. Moses, Christopher A. Kuhl, and Justin D. Templeton, NASA LaRC]**

However, quite a few enabling technologies remain to be developed and tested.

ACKNOWLEDGEMENTS

Discussions:

Dennis Bushnell, Peter Gnoffo, Mark Saunders, Charles McClish, Robert Dillman, Warren Kelliher, David Alexander, John Cole, Sergey Macheret, Reginald Exton, John Buckley, Dale Taylor, Douglas Tolbert, Joseph Parker, Nirvana Mehan, Erin Gatling, Melanie Fox, Daniel Chattin, Juan Cruz, Will Scott, and Robert Ash…

Graduate students:

Zhon Shi, Thao Dinh, Jan Drake, Brandon Rogers

Svetozar Popovic and Leposava Vuskovic gratefully acknowledge support of NASA Langley Research Center through ODURF Project #133931; (seek a NIAC grant to support more students…)